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THE USE OF SINGLE BEAM HOLOGRAPHIC INTERFEROMETRY IN TEMPERATURE MEASUREMENTS IN RECTANGULAR HEAT PIPE

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SINGLE BEAM HOLOGRAPHIC INTERFEROMETRY

Single beam holographic interferometry is a non-contact optical method and as such posesses considerable advantages, e.g. no inertial errors.This contributes to flexibility and enables observation of the transient processes, which would otherwise be hard to observe. Moreover, the measurement tèchnique covers a large portion of the measured field at the same time (with the same photograph), avoiding the need for point-by-point measurements.

To avoid confusion with the literature /1/, the expression 'single beam' will denote single wavelength measurements, although actually two beams are used. The laser beam is split into an object beam and a reference beam by an apparatus on air suspensed table. The reason for the use of a 'floating' table is the sensitivity of the measurement method to any disturbance from its surroundings, e.g. vibrations, caused by someone walking through the lab.

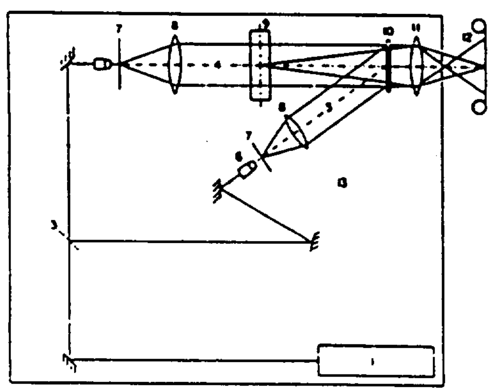

FIGURE 1. The Apparatus for Single Beam Holography Interferometry
1. Laser, 3. Variable Beam Splitter, 4. Object Beam,
5. Reference Beam, 6. Spatial Filter, 7.Pinhole,
8. Collimating Lens, 9. Test Section,
10. Holographic Plate, 11. Lens, 12. Camera,
13. Air Suspension Table, 14. Shutter.

To obtain results one observes two beams of the same wavelength with phase shift due to the change in the refractive index of disturbed system. We were using 4W water cooled laser with an ethalon, emitting a blue beam at 460 nm. The layout of the apparatus is displayed in figure 1. With single beam interferometry, the change in refractive index is the measured property. Refractive index is in general a function of temperature and density and is a material property. If only the temperature gradient is to be measured, one has to make sure that one works only with pure ingredients at constant density or with pure ingredients with a density which does not depend strongly on temperature. In this case, the difference in refractive index can be expressed as

$$S(x,y,t)\,\lambda = l\,\Delta n(\lambda) \tag{1}$$

where $S, \lambda, l, \Delta n$ are multiples of wavelength, wavelength, length of the test section and change in refractive index respectively. If, say, the temperature field dominates, Equation (1) can be approximated by

$$S(x,y,t)\,\lambda = l\,\frac{\partial n(\lambda)}{\partial T}\,\Delta T \tag{2}$$

Clearly, we can deduce a similar equation for a concentration field at constant temperature. The techniques used for actual measurements and derivation of equations will be described as a part of twin beam interferometry, as proposed by Mayinger and Panknin (1974) Therefore, single beam interferometry will be described together with twin beam interferometry techniques.

THE THEORY OF TWIN BEAM INTERFEROMETRY

The following assumptions are to be made in the development of the governing equations (Panknin 1977):

1. The optical system is perfect, the experimental setup is mechanically stable, and the lasers are ideal.
2. The object beams with the wavelengths λ_j and λ_k are ideal parallel waves.
3. The variation of refractive index is only two dimensional.
4. There is no reflection of the beam due to gradients of the refractive index.
5. Refractive index of the environment and of the test section (while recording comparison waves) is a constant.
6. The holographic construction is perfect.

We have assumed that the density is either constant or it is changing in the same manner as the temperature. Now, with possibility of recording results at different wavelengths, one can derive the system of equations for as many unknowns as wavelengths. However, since the change of refractive index is conditioned with temperature and concentration field, one needs to employ two different wavelengths as mentioned before. The object beam, passing through the test section at different times, is superimposed on the comparison wave, which is observed as the difference in optical lenghts of two exposures. This can be expressed in multiples S of wavelength λ as

$$S(x,y,\lambda) = l[n(x,y,\lambda) - n_\infty] \tag{3}$$

where l is the length of the test section, in which the refractive index varies. With this approach an average index change is observed. To get the change at the one point, one has to consider the distance between two fringes as a length of the test section.

An extinction of light (dark fringes) occurs for

$$|S| = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \ldots \tag{4}$$

and amplification (bright fringes) for

$$|S| = 1, 2, 3, \ldots \tag{5}$$

The interference fringes are points of the same refractive index change and can be thus associated with the points of the same temperature or concentration. In order to relate change of refractive index to the change of temperature and concentration, the "neutral" material property should be found. Such property is the molar refractivity $N(\lambda)$, which is related to the refractive index by Lorenz - Lorentz equation

$$N(\lambda) = \frac{n(\lambda)^2 - 1}{n(\lambda)^2 + 2}\,\frac{M}{\rho} \tag{6}$$

For the gases with refraction index $n \cong 1$, Equation (6) can be approximated by the Gladstone - Dale equation

$$N(\lambda) = \frac{2M}{3\rho}[n(\lambda) - 1] \tag{7}$$

If the further assumption is made that the working gas is nearly ideal, one can replace M/ρ with the total pressure p, temperature T, and universal gas constant, R, to get

$$N(\lambda) = \frac{2RT}{3p}[n(\lambda) - 1] \tag{8}$$

For the a mixture of gases, the molar refractivity is given by a linear combination of the molar refractivities of components weighted by their concentration

$$N(\lambda) = \sum_{m=1}^{q} C_m N_m \tag{9}$$

where q is total number of components in the mixture. Note also that

$$\sum_{m=1}^{q} C_m = 1 \tag{10}$$

Equations (3) and (8) yield the following expression

$$S\lambda_i = \frac{3}{2}\,\frac{lp}{R}\left[\frac{1}{T_i}\sum_{m=1}^{q} C_{mi}N_{mi} - \frac{1}{T_\infty}\sum_{m=1}^{q} C_{m\infty}N_{m\infty}\right] \tag{11}$$

Assuming $q = 2$ one can write the following equation, omitting the independant variables while describing dependant

$$S\lambda_i = \frac{3}{2}\,\frac{lp}{R}\left\{\frac{1}{T}[C_a(N_a - N_b) + N_b] \frac{1}{T_\infty}[C_a(N_{a\infty} - N_{b\infty}) + N_{b\infty}]\right\} \tag{12}$$

Since $N_a = N(\lambda)$, which implies that $N = N_\infty$

$$S\lambda_i = \frac{3lp}{2R}\left[N_a\left(\frac{C_a}{T} - \frac{C_{a\infty}}{T_\infty}\right) + N_b\left(\frac{C_a + 1}{T} - \frac{C_{a\infty}}{T_\infty}\right)\right] \tag{13}$$

or defining

$$\Delta N_j \equiv N_a(\lambda_j) - N_b(\lambda_j) \tag{14}$$

the final form of equations, used for determination of temperature and concentration in the flow field are found to be

$$T - T_\infty = \frac{S_j\lambda_j}{\Delta N_j} - \frac{S_k\lambda_k}{\Delta N_k} \tag{15}$$

and

$$C - C_\infty = \frac{S_j\lambda_j}{N_j} - \frac{S_k\lambda_k}{N_k} \tag{16}$$

The Single Beam Equations

The single beam equations, with which the corresponding temperatures and concentrations can be measured, are only the special cases of twin beam measurement techniques, in particular, when concetration equals unity. In that case, the Equation(13) becomes

$$S\,\lambda = \frac{3lp}{2R}\,N(\lambda)\left(\frac{1}{T} - \frac{1}{T_\infty}\right) \tag{17}$$

and finally

$$\boxed{\frac{1}{T} = \frac{1}{T_\infty} + \frac{2}{3}\,\frac{S\lambda R}{lpN}} \tag{18}$$

or, if we want to calculate the concentration with set $T = const$

$$\boxed{C = C_\infty + \frac{2}{3}\,\frac{S\lambda RT}{lpN}} \tag{19}$$

All of the equations above are derived for so called infinite mode.

The Finite Mode Single Beam Equations

For the finite fringes the system of calculations is somewhat different. To achieve the finite fringes mode, one has to disturb the system initially by changing some of its important physical parametrs. During our experiments we have achieved this by changing the properties of the spatial filter. In that case one has two reference temperatures, one arbitrarily set, and one at which the initially state is recorded. The advantage of this method is that although the molar refractivity is still the function of the wavelength and material properties, it is determined by the initial state of the system, i.e. by initial number of the finite fringes. In that case Equation (18) becomes

$$\frac{1}{T} = \frac{1}{T_\infty} + \frac{2}{3}\,\frac{S\lambda R}{lpN_{fin}} \tag{20}$$

This yields

$$N_{fin} = \frac{2}{3}\,\frac{S_{fin}\lambda R}{lp}\,\frac{TT_\infty}{T_\infty - T} \tag{21}$$

where T is the actual temperature and T_∞ is arbitrary, typically the boiling temperature. We can employ N_{fin} instead of our previous molar refractivity in Equations (18) and (19) to calculate temperature and concentration respectively.

As an example for finite fringes we recorded the picture, showing the heat pipe in steady state mode of operation.

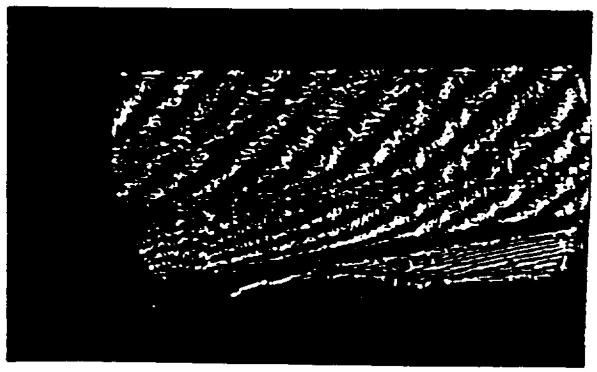

FIGURE 2. The Finite Fringes in the Heat Pipe.

THE EXPERIMENT

The object of our investigation is a rectangular heat pipe. This device is used for a transfer of heat by evaporating and condensing the fluid. A wick structure is used to return the condensed fluid, therefore the effects of capillary forces in the wick are employed. For transfer of the vapour from evaporating to condensing zone, the pressure difference is used. As a transporting media, the latent heat of evaporation is exploited. The working liquid is evaporating on the heated side and thus uses the energy contributed to the heat pipe. On the cooled side, the vapour is condensed and via that phenomena the heat is released. The experimental setup is shown in Figure 3.

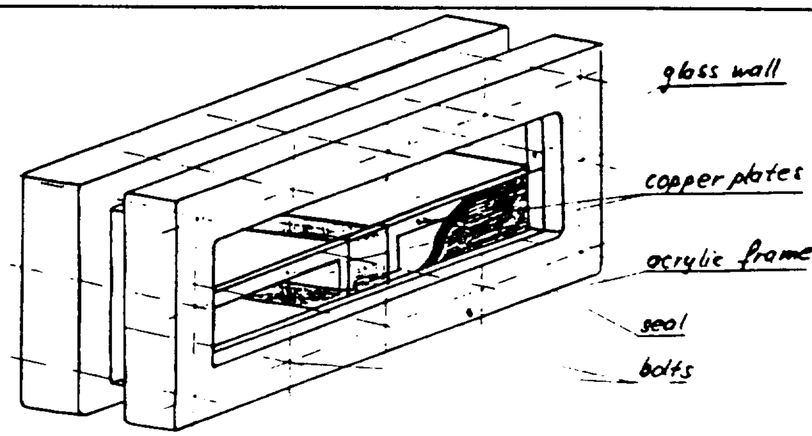

FIGURE 3. The Experimental Heat Pipe.

The goal of this experiment was to measure temperatures in a rectangular heat pipe. In order to simulate proper boundary condition, the upper boundary, which simulates the centerline of the heatpipe, was made of acrylic with low thermal conductivity. The lower boundary was made of copper plate, heated on the left side with two 6.4 $10^{-4} m^2$ large patch heaters, and cooled on the right with counterstream cooling system, attached to a technical water tube system. The medium we have worked with was $C_2Cl_3F_3$, also known as Freon 113, which is quite agressive, but its main advantage is convenient boiling point temperature.

STEADY - STATE RESULTS

The goal of this experiment is to establish a relationship between the power, used for heating the heat pipe and the actual temparature in the flow field. This would enable us to study the temperature patterns in the heat pipe during the operation as well as yiels data for computer model assesment.

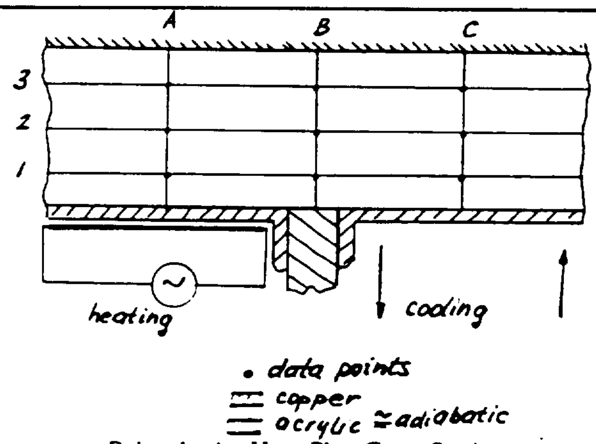

FIGURE 4. Measurement Points in the Heat Pipe Cross Section.

The heat pipe was divided into three sections, each with three levels, as indicated in figure 4. The results are tabulated and presented in form of graphs for each cross section A, B and C giving temperature as a function of position and power. The power is the input power to the patch heaters. Interesting result is seen in the cross section B, where temperature along Y axis almost does not vary.

TRANSIENT RESULTS

The goal of this experiment was to determine, how fast the temperature field in the heat pipe achieves its steady-state value. In order to record this development, a series of photographs were taken, describing the development of the temperature field at a constant power. The width of the test section was $0.02064 m$, the power on heaters was $2.4 W$. The graphs, for sections A, B, C as a function of position and time are presented. The transient observed is very slow, which implies that the period in which the heat pipe reaches its optimum heat transfer rate is rather long. This could be used as a suggestion for future experiments (to find a way how to shorten the "warm up" period).

CONCLUDING REMARKS

Both experiments are single beam holography interferometry, however they were needed to conquer the techniques needed for using twin beam holography interferometry as well as understanding and calibrating the previously mentioned computer code. For the quantitative comparison they ought to be scaled and than compared.

The steady state results show that the temperature gradient in the vapour region becomes greater with increasing power. This shows that the heat pipe accomodated higher heat transfer rates with increasing input power. The next step would probably be to find the limiting input power, and investigate theoretically determined limits on the heat pipe steady state operation. The transient results show that the transient period is quite long. It would be interesting to observe the change of the imposed limits on heat pipe heat transfer during the transient operation, which could lead to better understanding its possibilities and behaviour.

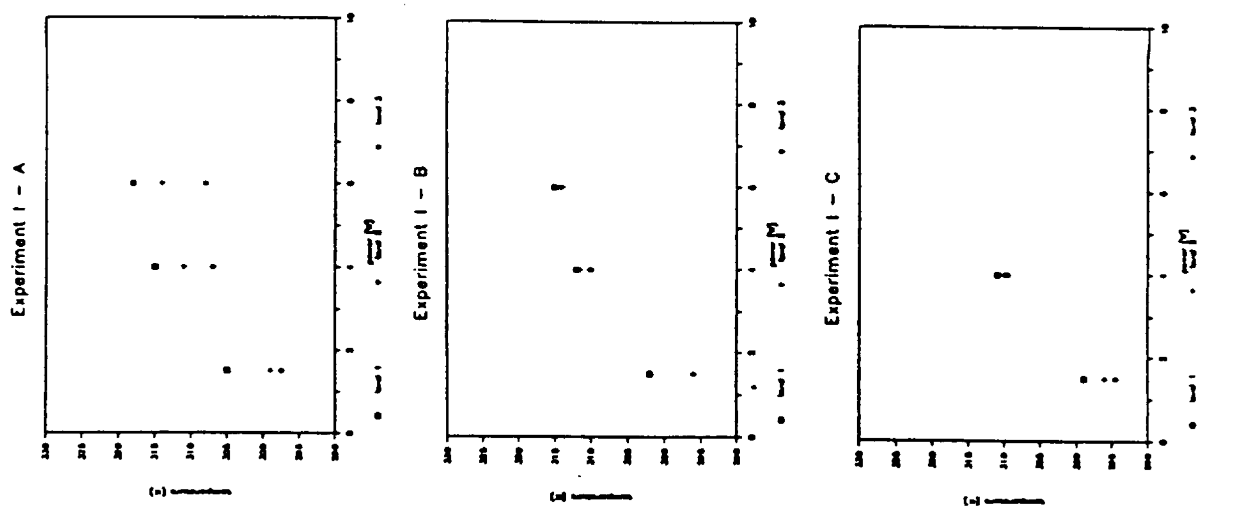

FIGURE 5. Temperature versus Power in Steady State Experiment.

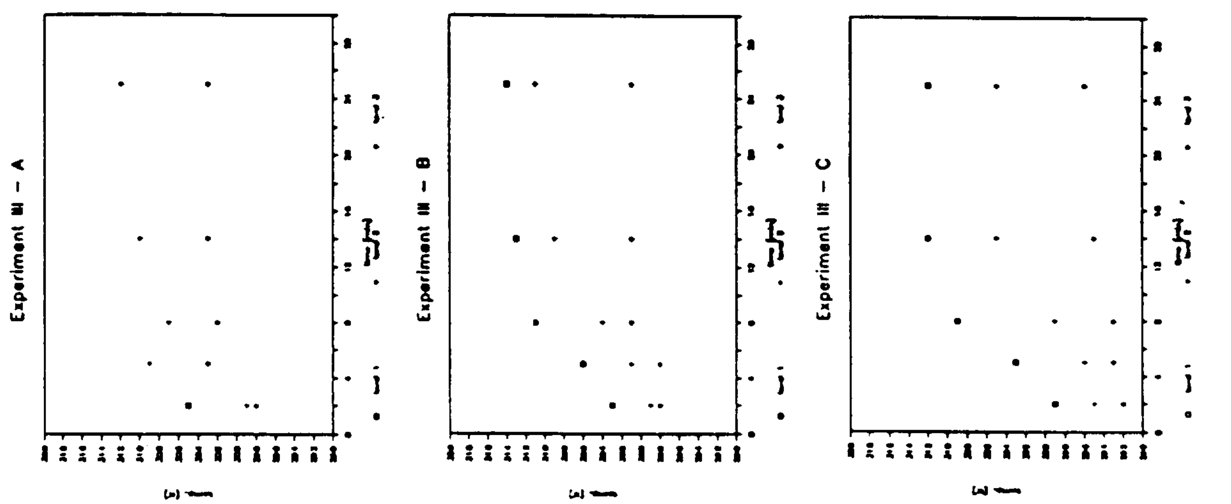

FIGURE 6. Temperature versus Time at Constant Power = 2.4 W.

Acknowledgments

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